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ENERGY CONSERVATION BY REDUCTION OF FORGING TEMPERATURE FOR PROJECTILES

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This project was accomplished as part of the U.S. Army's Manufacturing Methods and Technology Program. The primary objective of this program is to develop, on a timely basis, manufacturing processes, techniques, and equipment for use in production of Army materiel.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The 155-mm M107 projectile was tested at Scranton Army Ammunition Plant at reduced forging temperatures to determine the minimum acceptable forging temperature. During the pilot study, projectiles were forged in experimental groups of 50 each at five furnace temperatures, in decrements of 37.8°C (100°F)--starting at a baseline temperature of 1,204°C (2,200°F) and ending at 982°C (1,800°F). During production evaluation, 7,539 projectiles were forged without incident at the minimum acceptable forging temperature established in the pilot
(cont)

study; namely, 1,093°C (2,000°F). From a baseline tonnage of approximately 5.3 MN (600 tons), forging tonnage increased linearly by approximately 890 kN (100 tons) per temperature decrement.

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INTRODUCTION

Heating of steel used in forging of artillery projectiles is the single largest energy consuming operation in the manufacture of this hardware. The objective of this project was to reduce energy consumption in forging of projectile bodies by reduction of the forging temperature.

Current forging practice is to use a furnace temperature of 1,204°C (2,200°F) to heat the steel to 1,093°C (2,000°F) for forging. At a facility like the Scranton Army Ammunition Plant (SAAP), where this project was conducted, there are six rotary-hearth furnaces, each of which consumes 609m^3 (21,500 scf/h) of natural gas when operating at 1,204°C (2,200°F). A typical furnace is designed to heat 180 steel slugs (mult) weighing 50 kg (110 lb) each per hour to 1,093°C (2,000°F). Efficiency associated with this operation is shown below.

Heat input to steel:

$$180\ \frac{\text{mults}}{\text{h}} \times 50\ \frac{\text{kg}}{\text{mult}} \times 712\ \frac{\text{J}}{\text{kg-K}} \times (1{,}366\ \text{K} - 294\ \text{K}) = 6{,}869\ \frac{\text{MJ}}{\text{h}}$$

$$\left\{180\ \frac{\text{mults}}{\text{h}} \times 110\ \frac{\text{lb}}{\text{mult}} \times 0.17\ \frac{\text{Btu}}{\text{lb-}^0\text{F}} \times (2{,}000\,^0\text{F} - 70\,^0\text{F}) = 6{,}496{,}380\ \frac{\text{Btu}}{\text{h}}\right\}$$

Gross heat input to furnace:

$$609\ \frac{\text{m}^3}{\text{h}} \times 38{,}377\ \frac{\text{kJ}}{\text{m}^3} = 23{,}372\ \frac{\text{MJ}}{\text{h}}$$

$$\left\{21{,}500\ \frac{\text{scf}}{\text{h}} \times 1{,}030\ \frac{\text{Btu}}{\text{scf}} = 22{,}145{,}000\ \frac{\text{Btu}}{\text{h}}\right\}$$

Efficiency:

$$\frac{6{,}869\ \frac{\text{MJ}}{\text{h}}}{23{,}372\ \frac{\text{MJ}}{\text{h}}} \times 100 = 29\%$$

While the efficiency of these furnaces is quite low, it is better than the reported efficiency of many gas-fired forging furnaces used throughout industry, where efficiencies as low as 15% are reported. As the operating temperature of a furnace increases, the efficiency goes down; therefore, it was reasoned that, by reduction of the forging temperature, significant energy savings could be realized beyond that which could be expected from reduction of the mult temperature.

The heat balance shown in figure 1 graphically illustrates that forging furnaces are a very fertile field for energy conservation. As shown, 71% or 16,353 MJ/h (15,500,000 Btu/h) of the 23,211 MJ/h (22,000,000 Btu/h) heat input from gas is currently being wasted. Furnace losses—which include heat losses through furnace walls, radiation losses through charge and discharge doors, and

losses associated with evaporation of water which serves as a gas seal around the periphery of a rotary hearth--account for 18% of the heat input energy. The remaining 53% of heat input is being discharged as wasted heat by flue gases through the furnace stack.

It may seem that reduction of the forging temperature would not significantly affect energy consumption since only 29% of the heat input is being used to heat the steel. However, the overall operating efficiency of the furnace is improved when it is operating at reduced temperatures, and it is this effect which actually produces significant energy savings during operations with reduced forging temperatures.

Three major questions that were associated with use of a reduced forging temperature were addressed during this project:

1. Would the forging presses have sufficient tonnage capacity?

2. What would be the impact on forge tool life?

3. How would projectile quality be affected?

It was recognized that use of reduced forging temperatures would result in increased press tonnage due to the reduced plasticity of steel at lower forging temperatures. Therefore, the degree of tonnage increase had to be determined so that a reduced forging temperature could be selected that would result in tonnages within the capacity of available forging press equipment.

Also, the impact of reduced forging temperatures on forge tool life was to be determined. On the one hand, expected increases in press tonnage suggested that forge tool life might be reduced due to increased loading on the forge tools. Conversely, reduced steel temperatures might result in reduced heat buildup in the tooling, which would tend to prolong tool life.

Finally, and probably of most importance, it was necessary to determine the impact on projectile quality when forging occurred at reduced temperatures. Potential dimensional variations had to be evaluated and, if necessary, tooling adjustments implemented. Projectile cavity quality needed careful evaluation because it was possible that, by operation at reduced furnace temperatures, less scale would be produced on the mult, and an improved projectile cavity in terms of scale-type defects might be achieved.

PILOT STUDY

Background and Procedure

The objective of the initial effort under this project was to establish a reduced forging temperature that would produce quality 155-mm M107 forgings at forging press tonnages within the available press capacities at Scranton Army Ammunition Plant. To accomplish this objective, 155-mm M107 forgings were made

in experimental quantities of 50 pieces each at five forging furnace temperatures in 37.8°C (100°F) increments, starting at 1,204°C (2,200°F) [current normal forging furnace temperature] and ending at 982°C (1,800°F). A pilot study was needed to determine the tonnage increase associated with reduced forging temperatures and to initially assess projectile dimensions and surface finish quality. Data gathered during the pilot study included measurement of workpiece temperatures and press tonnage and an assessment of forging quality. An attempt was made to measure furnace energy consumption and forge tool life; however, these factors could not be meaningfully assessed because of the small number of forgings produced at each temperature and because of the furnace adjustments required.

The Verson forging press line at SAAP was used for the pilot study. This line consists of a 13.345 MN (1,500 ton) hydraulic pierce press, which was double tooled to do both the preform and piece operations; a 2.224 MN (250 ton) hydraulic draw press; and a Selas forging furnace.

In practice, it proved difficult to reduce the temperature in the Selas furnace to 1,038°C (1,900°F). The specific problem was that certain minimum gas and air flow rates are required through the burners to provide cooling and to prevent damage to the burner tips. At these minimum gas and air flow rates, temperatures in zone 2 of the 3-zone furnace could not be reduced to 1,038°C. For this reason, it was decided to process the 982°C (1,800°F) and 1,038°C groups by heating only in zone 3 of the furnace. This decision necessitated the reduction of the number of pieces in these two groups to 30 forgings each.

Furnace Versus Workpiece Temperature

Up to this point, all reduced forge temperatures have been discussed in terms of the furnace temperature. It is of interest to know the relationship between furnace temperature and workpiece temperature. To obtain this relationship, workpiece temperatures were measured at the furnace exit, at the entrance to the preform forge station, and at the exit of the draw press. A graph showing furnace temperature versus workpiece temperature at these three points in the forge process is shown in figure 2. This graph shows that the temperature of the mult exiting the furnace was 38 to 80°C (100 to 175°F) lower than the furnace temperature, depending upon the furnace temperature. The reason for this is that the mult is not in the furnace long enough to reach furnace temperature, coupled with the fact that any scale present on the mult will tend to cause the surface temperature measuring instrumentation to read lower than the actual temperature. Upon exiting the furnace, the mult traveled down a roller conveyor to the forge press. During this period of travel, the mult lost an additional 4.4 to 24°C (40 to 75 °F), depending upon furnace temperature, with the higher losses occurring at the higher temperatures. The temperature of the workpiece after draw was reduced by 66 to 121°C (150 to 250°F) below the mult temperature immediately prior to forge. The temperature of the workpiece after draw was nearly a linear function of furnace temperature, with the workpiece draw temperature being approximately 221°C (430°F) below the furnace temperature.

Press Tonnage Measurements

Press loads at normal furnace temperature and the reduced furnace temperatures were measured. The change in pierce, preform, and draw tonnage as the furnace temperature is reduced from the normal temperature of 1,204°C (2,200°F) is shown in figure 3. The pierce and preform tonnage decreased as the furnace temperature was lowered from 1,204°C to 1,149°C (2,100°F), then started a linear increase as furnace temperature was lowered to 982°C (1,800°F).

Based on subsequent results achieved in the production evaluation, it appears that the tonnage measurements taken at a furnace temperature of 1,204°C (2,200°F) were in error. These measurements show that the average pierce and preform tonnages at a furnace temperature of 1,204°C were 5.231 and 5.061 MN (588 and 569 tons), respectively. Substitution of these values in figure 3 makes the plots for pierce and preform tonnage almost linear, with a nearly constant increase in press tonnage of approximately 0.890 MN (100 tons) for each 38°C (100°F) decrease in furnace temperature. Inspection data indicated that the projectiles forged at 1,204°C had more scale than those forged at reduced forging temperature. This increased scale was indicated by the high percentage of forgings with cavity scale holes in the workpieces that had been forged with 1,204°C furnace temperature. The exact cause of the thicker scale is not known, but increased scale could account for the higher tonnage recorded at 1,204°C.

Very little change in draw tonnage occurred at any of the temperatures investigated. The average draw tonnage varied from 770 to 903 kN (86.5 to 101.5 tons) for the five forging temperatures investigated. These tonnages are well below the 3.559 MN (400 ton) rated capacity of the draw press.

For the Verson forge press, the tonnages were well within the 13.345 MN (1,500 ton) press capacity for all reduced forging temperatures evaluated; however, there is an Erie forge press line at SAAP that uses a hydraulic forge press rated at 7.117 MN (800 tons). It was desirable to select a reduced forge temperature which could be applied to both the Bliss and Erie forge press lines used at SAAP for manufacture of the 155-mm M107 projectile. Referring to figure 3, a furnace temperature of 1,093°C (2,000°F) is the lowest furnace temperature that can be used without exceeding the pierce press tonnage of 7.117 MN (800 tons).

Energy Consumption

Gas usage readings were taken at the start of furnace loading for each furnace temperature and at the time the last mult was discharged from the furnace. The gas usage at each furnace temperature is shown in table 1. Gas usage decreased for the first two furnace temperature reductions, increased for the next 37.8°C (100°F) temperature reduction, and then decreased for the final temperature reduction. The unexpected increase in gas consumption when going from a furnace temperature of 1,093°C (2,000°F) to 1,038°C (1,900°F) is attributed to the fact that in order to reduce the furnace temperature to 1,038°C, the minimum air flow for zone 2 in the Selas furnace was increased from 283 m^3/h (10,000 scf/h) to 708 m^3/h (25,000 scf/h) because of concern that the burner tips in zone

2 would overheat because of low gas and air flow. Since the furnace operates on a specific gas and air ratio, gas usage increased accordingly.

Subsequent investigations established that the Hagan ring balance flow meter being used to measure gas consumption was not an accurate instrument. The results of the pilot study clearly indicated substantial energy savings should be possible when the furnace was operating at reduced forging temperatures; however, any accurate assessment of energy savings would require forging of a larger quantity of projectiles at both normal and reduced forging temperatures.

Inspection Data

Inspection data was collected on the projectiles forged during the pilot study. The small number of pieces forged at each temperature made it difficult to draw meaningful conclusions relative to this inspection data. For any given temperature, tooling adjustments could have been made to correct the fact that some forgings were falling outside of dimensional control limits; however, such tooling changes could not be practically accomplished because of the small number of pieces being forged at each temperature.

In terms of forging dimensions, the pieces forged at reduced forging temperatures appeared to be no worse than forgings made at normal forging temperature. After heat treatment and finish machining, all the pieces were processed into acceptable projectiles. In fact, one conclusion might be that the pieces handled at reduced forging temperatures were better dimensionally than the pieces handled at regular temperature. After finish-turn there were seven dimensional rejects from pieces forged at the 1,204°C (2,200°F) furnace temperature versus only two dimensional rejects for pieces forged at all of the reduced forging temperatures.

The surface finish and metal defect characteristics of the projectile forged at reduced temperatures were at least equal to those of projectiles forged at normal temperatures. Although the projectiles forged at 1,204°C (2,200°F) had more scale holes than projectiles forged at the reduced temperature, this condition is not believed to be typical of projectiles forged at regular forging temperature and, therefore, valid comparisons cannot be made.

Tool Life

As far as the forge tooling is concerned, the pierce and ejector tips are replaced most often; however, these two pieces of tooling typically have a life of over 1,000 projectiles before they must be replaced. Fifty forgings per furnace temperature was not sufficient to draw any conclusion with respect to forge tool life, and no data was gathered relative to this aspect.

Rough-turn tool replacement is shown in table 2.

Increased rough-turn tool wear in the pilot quantities was attributed to the fact that many forgings did not fall within the desired forge dimensional control

limits. If forge tool adjustments could have been made so that forgings more nearly met the desired dimensional control limits, it is believed that rough-turn tool life would have increased to the level experienced in regular production.

PRODUCTION EVALUATION

Background and Procedures

The purpose of the production evaluation was to confirm that it is technically and economically feasible on a production basis to reduce forging temperatures during forging of the 155-mm M107 projectile Results of the pilot study clearly indicated the need for processing of a larger quantity of projectiles at both normal and reduced forging temperatures in order to obtain meaningful comparisons of factors such as energy savings, projectile quality, and tool life. The production evaluation was conducted to address these factors.

Production evaluation consisted of data collection for a 1-month production period when projectiles were forged at the normal furnace temperature of 1,204°C (2,200°F). A total of 20,537 projectiles were forged at 1,204°C. This data was then used as a basis for comparison with data obtained during processing of 7,539 projectiles forged at a reduced forging furnace temperature of 1,093°C (2,000°F). These projectiles were forged during a 1-week production period. The furnace temperature of 1,093°C appeared to be the minimum temperature which could be considered based on the 7.117 MN (800 ton) maximum capacity of the Erie press line used at SAAP in manufacture of the 155-mm M107 projectile.

Data that was monitored and recorded during the production evaluation is listed below:

1. Natural gas consumption of the forge furnace

2. Electrical consumption of the forge furnace and press

3. Forging press loads

4. Mult temperature prior to the preform operation

5. Tool usage of both the forging and rough-turn operations

6. Pertinent inspection results through the production process

The first thing that was done as part of the production evaluation was to install a Roots gas meter for accurate measurement of natural gas consumption. Wattmeters were also used to measure electrical consumption of the forge furnace and press. Forging press loads and mult temperature prior to preform were monitored to make sure that results did not vary from results recorded in the pilot study.

All forging done during the production evaluation was performed in the Bliss I forge line, which consists of one 2.224 MN (2,500 ton) mechanical press equipped with a 9.786 MN (1,100 ton) safety overload system--double tooled to do both the preform and pierce operations--and one 3.559 MN (400 ton) hydraulic press for hot draw. For heating of mults, this forge line has a Surface Combustion rotary-hearth furnace that is direct fired. All projectiles made during the production evaluation were processed through the complete production sequence with the use of normal processing and inspection techniques, with the exception that 7,539 projectiles were forged at a reduced furnace temperature of 1,093°C (2,000°F) in lieu of the normal 1,204°C (2,200°F). For the purpose of obtaining a comprehensive analysis of energy consumption, energy readings were recorded according to the following classifications:

Production Condition

This condition includes the actual hours of operation for any given production shift. During operation at normal forging temperature only the first shift was monitored. For the reduced temperature test both the first and second shift were monitored.

Continuous Operation Condition

This condition includes the 24 hours that the furnace operates per day. On weekdays no production is run on the third shift, but the furnace is loaded with mults and is in a hold-loaded operating condition. However, the furnace is turned off on weekends for approximately 27 hours, and there is a 29-hour startup period after shutdown.

A breakdown of operating conditions of the furnace on a weekly basis is shown below:

Condition	Hours
Production	80
Hold-loaded (overnight)	32
Startup	29
Total continuous operating hours per week	141
Furnace shut off for weekend	27
Total hours in week	168

Miscellaneous Condition

This condition includes startup, loading, hold-loaded, and unloading.

Furnace zone temperatures for the reduced operating temperature phase of the project were all reduced by 93°C (200°F) from the normal operating temperature. The reduced temperature zone settings were as follows:

Zone 1 - 982°C (1,800°F)
Zone 2 - 982°C (1,800°F)
Zone 3 - 1038°C (1,900°F)
Zone 4 - 1093°C (2,000°F)

Instruments used to measure press tonnage, furnace and mult temperature, and energy consumption of the furnace and press are:

Measurement	Instrument
Furnace temperature	Hagan recorder, assy 177050-2202011 (regular furnace recorder)
Mult temperature	Ircon infra red recorder, mod 11-2923-32, channel 1
Press tonnage	Gould brush recorder mod 11-2923-32, channel 2
Furnace gas usage	Roots gas meter, mod 38M125ID Root data module, mod 288
Furnace and press electrical usage	Esterline-Angus wattmeter recorder, mod 601-C, Esterline-Anugs watthour register 6152R

Energy Consumption

Tables 3 and 4 contain a summary of energy usage for all of the operating conditions measured during the production evaluation. The average gas consumption during production operation was 610 m^3/h (21,558 scf/h) for normal operating temperature and 454 m^3/h (16,040 scf/h) for the reduced operating temperature, or a 25.6% reduction in natural gas consumption when the reduced forging temperature was used.

For continuous operation, which includes weekend startup and third shift hours, average gas consumption at normal furnace temperature of 1,204°C (2,200°F) was 462 m^3/h (16,332 scf/h) versus 363 m^3/h (12,787 scf/h) at a reduced furnace temperature of 1,093°C (2,000°F). This operation results in a gas savings of 100 m^3/h (3,545 scf/h), or an annual savings, based on 7,050 total furnace operating hours per year, of 708,000 m^3 (25 million scf) of natural gas.

At the current natural gas prices at SAAP of $3.40 per 28 m^3 (1,000 scf) and under operating conditions that existed at the time of this work (2-8-5 shift basis) natural gas reduction from use of a reduced forging temperature would result in an annual savings of $85,000 per year per operating furnace.

Under mobilization conditions (3-8-5 shift basis) natural gas savings would increase to $112,000 per year per operating furnace.

The gas and hour figures listed in table 3 for production, hold-loaded, unloading, loading, and startup conditions do not add up to the gas and hour figures for continuous operation. The production figures include allowance for any other condition which occurred during the 8-hour shifts. Therefore, the production gas and hour figures listed in table 3 include not only the gas usage during forging but also the gas usage during any hold-loaded condition that occurred during the production shift.

The various operating conditions of the furnace all reveal a decrease in gas consumption when the furnace is operated at the reduced forging temperature. The loading condition shows an exceptionally high reduction in gas usage, for which there is no rational explanation. The loading condition also shows an exceptionally high reduction in electrical usage under reduced forge temperature operation; this reduction would lead one to believe there may have been an error in the recording of the number of hours the furnace was in a loading condition.

A comparison of electricity usage in table 4 reveals a slight increase in press consumption of 8 MJ (2 kWh) and a slight decrease in furnace consumption of 14 MJ (4 kWh) for production operation during operations at a reduced forge temperature. All other furnace conditions except continuous operation indicate a reduction in electricity usage. Continuous operation showed an 8 MJ (2 kWh) increase in electricity usage for reduced forge temperature operation. To obtain an overall comparison of electricity usage under continuous operation conditions, the press and furnace energy usage can be combined. To make a valid comparison of electrical usage under continuous operation, the press electrical usage at normal furnace temperature must be doubled, since only the first shift energy usage was recorded. If this usage is doubled and if press and furnace electricity usage are combined, the hourly electricity usage for normal forge temperature is 1,360 MJ (378 kWh) versus 1,350 MJ (375 kWh) for reduced forge temperature operation. This difference in electricity usage is rather insignificant and can, for all practical purposes, be disregarded.

Table 5 shows the power demand for the various operating conditions of the furnace and forging press. These figures were taken from recording charts that showed electrical demand for the furnace and press. These figures show a 5-kW reduction in electricity demand for the hold-loaded and the production operation conditions during operation at reduced temperatures. A demand increase of 24 kWh is shown for the pierce operation and an increase of 48 kWh for the combined pierce-and-draw operation. This increase in electricity demand can be attributed to the increased loads that are required to forge the projectiles during the pierce-and-draw operation while the furnace is at a reduced temperature. The preform operation shows a reduction in electricity demand of 72 kWh while the furnace is at the reduced temperature. This decrease cannot be directly related to reduced forging temperature since the power demand of this operation is more directly related to mult weight; that is, the heavier the mult, the larger the tonnage and corresponding power demand that will be required to complete the preform operation.

Forging Tonnage

Forging press loads--minimum, maximum, and average--and corresponding mult temperatures during forging at both normal and reduced temperatures were recorded at random intervals throughout the test (table 6). These values are representative of all operating conditions of the furnace and press.

The Bliss mechanical press used for this test is equipped with hydraulic pressure overload protection which is designed to allow maximum loads of 9.786 MN (1,100 tons) before press shutdown occurs. Due to problems encountered with the pilot pressure relief valve located in the overload circuit, maximum pilot pressure needed to allow maximum forging loads of 9.786 MN could not be attained. For this reason true values of the maximum loads could not be established. With reference to table 6, the maximum loads shown for the preform and pierce operation represent maximum readings recorded when overload occurred and, therefore, do not represent true maximum loading figures which would have been experienced had the overload protection system not been activated.

Press overloads occurred primarily during forging of the last ten mults that were part of the load held in the furnace overnight. The mults in this part of the overnight hold-loaded operation had become more heavily scaled, which probably accounted, at least in part, for the high press loads required to forge these mults. Some overloads did occur after break and lunch periods for these same reasons. Other reasons for higher press tonnage after downtime periods could be cold tooling and reduced temperature of mults because they were sitting next to the discharge door of the forge furnace for extended periods of time. Application of additional lubricant to the die during forging of the first few pieces after downtime helped to prevent the press overload condition.

Individual tonnage readings on the preform operation are not meaningful in terms of reduced forging temperatures since the preform tonnage is highly dependent on preform weight. On an average basis, the preform tonnage increased by 0.863 MN (97 tons) during operation at the reduced temperature.

The minimum pierce loads, as indicated in table 6 show an increase of 1.610 MN (181 tons), whereas the average pierce load increased by 1.628 MN (183 tons) when forged at the reduced temperature. These results are in close agreement with results of the pilot study, where a press load increase of 0.890 MN (100 tons) for each 38°C (100°F) decrease in furnace temperature was experienced.

The minimum, maximum, and average draw loads increased by 0.142 MN (16 tons), 0.177 MN (20 tons), and 0.044 MN (5 tons), respectively, during forging, at the reduced temperature.

Prior to press tonnage measurements the temperature of the mult before it entered the forge press was taken at random intervals throughout the test. Normalized data, graphically shown in figure 4, shows the frequency of mult temperatures within the 10°C (50°F) temperature intervals depicted. Mult temperatures ranged from 927°C (1,700°F) to 1,093°C (2,000°F) during operation at a reduced furnace temperature of 1,093°C with an average mult temperature of 999°C (1,830°F). At the normal furnace temperature of 1,204°C (2,200°F), the mult

temperatures ranged from 982°C (1,800°F) to 1,149°C (2,100°F), with an average mult temperature of 1,093°C. This data shows that on the basis of both minimum temperatures recorded and average temperature there was less heat loss in mults heated at reduced furnace temperature than in those heated at normal furnace temperature. This result would be expected on the basis of the more rapid heat loss to the atmosphere for mults heated to the higher temperature. In terms of being able to forge at reduced temperatures, the most significant fact is that there was only a 37.8°C (100°F) temperature differential between the minimum mult temperatures for forging at normal and for forging at reduced temperatures--even though there was a 93°C (200°F) difference in furnace temperature. The minimum mult temperature would be expected to be the controlling factor in terms of maximum press tonnage, and the data indicates that when furnace temperature was lowered 93°C, the minimum mult temperature only decreases 37.8°C (100°F).

Maximum, minimum, and average press tonnages are plotted against specific mult temperature ranges [10°C (50°F) intervals] in figure 5. Within the mult temperature range where the plots for reduced and normal forge temperatures overlap [982 to 1,093°C (1,800 to 2,000°F)] press tonnage would be expected to fall within the same range for any given mult temperature. The fact that this was not found to be true, particularly with respect to maximum and minimum tonnage values, suggests that there are other factors besides mult temperature which are directly related to forging tonnage. Other factors which could affect forging tonnage are: the time the mult is in the forge furnace, the amount of scale on the mult, the degree of tool wear, and the condition of forge tooling lubrication. The fact that the greatest difference between minimum and maximum tonnage occurs at those temperature intervals where the greatest number of readings were taken (for both normal and reduced temperatures) (fig. 4) is another indication that factors other than mult temperature influenced press tonnage. This result occurs because the only way to collect data representative of all operating conditions is by taking a large number of tonnage measurements. Analysis of figure 5 suggests that to establish any relationship between mult temperature and press tonnage only average press tonnage values should be considered; then, a fairly linear decrease is shown in press tonnage of 0.756 MN (85 tons) per 37.8°C (100°F) increase in mult temperature.

Tool Life

Tool usage of both the forging and rough-turn operations was monitored and recorded (table 7). A significant decrease in forge tool life occurred for the pierce tips and draw rings during operation at the reduced temperature. The 15% decrease in pieces-per-tool for the pierce tip is not too surprising because of the increased tooling stresses resulting from the higher tonnages at the reduced temperature. The validity of the 72% decrease in tool life for the draw rings is questionable. The tool life values for both normal and reduced forging temperatures were obtained from one set of draw rings. The 54,227 pieces-per-tool for the normal forge temperature is considerably higher than normally experienced. Because this figure is questionable in terms of tool life that can be expected of draw rings on a consistent basis, and because the data in both instances represents only one set of draw rings, a realistic comparison of tool life for draw rings cannot be made on the basis of the data gathered.

As shown in table 7, an apparent decrease in rough-turn tool life occurred when projectiles were forged at the reduced temperature. This fact is unexplainable since there should be no difference in metallurgical characteristics between the normal and the reduced temperature forgings. However, operating personnel pointed out that machine tool problems were being experienced at the time the reduced temperature forgings were processed, and this fact may account for the decreased tool life. Also, the contractor stated that, since substantial variations in tool life are experienced from time to time in the rough-turn machine area, the short span of 5 days (when the reduced temperature forgings were processed) does not represent a long enough period to reach any meaningful conclusions.

Projectile Quality

The following inspections and measurements were made to compare projectile quality and metallurgical characteristics of projectiles forged at normal and at reduced temperatures:

1. Hot forging dimensions (lower datum and cavity lengths, base thickness, and concentricity at three sidewall locations)

2. Visual inspection after forge (scale and tool marks)

3. Visual inspection after shot blast (base and wall laminations, scale, tool marks, and scale holes)

4. Volume check after nosing

5. Mechanical properties after heat treatment

6. Projectile weight at final inspection

7. Overall scrap rate

An analysis of the inspection results showed that for all the above items, the projectiles forged at reduced temperatures were no different from projectiles produced under normal forging temperature conditions. The overall scrap rate for the quantity of projectiles made at the reduced forging temperature was slightly lower than the scrap rate for the quantity of projectiles made at the normal forging temperature. However, the contractor stated that the scrap rate varies from month to month; therefore, a continuous evaluation of scrap rates for some significant length of time, with furnace at a reduced temperature, would be required to confirm these results.

CONCLUSIONS

The following conclusions were made:

1. Gas savings of 100 m^3/h (3,545 scf/h) amounting to $85,000 per year can be achieved at Scranton Army Ammunition Plant under 2-8-5 shift operating conditions (one furnace in operation) by use of a reduced forge temperature of 1,093°C (2,000°F).

2. A slight decrease in electricity consumption occurred when a reduced forging temperature of 1,093°C was used. Press hourly electricity usage increased by 8 MJ (2 kWh), while furnace hourly electricity consumption decreased by 14 MJ (4 kWh).

3. Increased press tonnages occurred during operation at a forging temperature of 1,093°C. Average tonnage of the forging and draw presses increased by approximately 17%, 31%, and 3.6% for the preform, pierce, and draw operations, respectively.

4. Increased tool wear occurred during operation at reduced forge temperatures; however, additional monitoring of tool usage is required to verify these results.

5. Projectile quality during operation at reduced forge temperatures improved slightly compared to projectile quality normally experienced.

6. Forgings manufactured at reduced forging temperature exhibited the same dimensional tolerances as forgings manufactured at normal operating temperatures.

RECOMMENDATIONS

The following recommendations are made:

1. A reduced forge temperature of 1,093°C (2,000°F) at Scranton Army Ammunition Plant should be implemented.* During the first several months' production, tool usage should be monitored to establish meaningful tool life data.

2. Since forging tonnage requirements cannot be directly translated from mechanical presses to hydraulic presses due to differences in ram speeds, limited

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* Since completion of this project, a reduced forge temperature has been implemented at Scranton Army Ammunition Plant. Energy data collected since implementation indicates a savings of $0.17 per projectile, which translates into over $100,000 per year savings at a production rate of 50,000 projectiles per month. Tool usage data has shown no difference in tool life because of operation at the reduced forge temperature.

trials with reduced forging temperature should be run on the 7.117 MN (800 ton) hydraulic presses at Scranton Army Ammunition Plant to establish that these presses have the required tonnage capacities to operate at reduced forge temperatures.

3. Some means of providing an incentive to GOCO plant operators to save energy should be developed. Because the Government pays the utility bill at GOCO plants and because there is a natural tendency to continue the status quo, it may be difficult to get operating contractors to use a reduced forging temperature unless an incentive is provided.

Table 1. Gas usage with furnace operating at various temperatures (pilot study)

Furnace temperature °C	°F	Gas usage m^3/h	cu ft/h
1,204	2,200	739	26,108
1,149	2,100	652	23,040
1,093	2,000	484	17,082
1,038	1,900	600	21,176
982	1,800	465	16,421

Table 2. Rough turn tool replacement (pilot study)

Furniture temperature °C	°F	Tools replaced
1,204	2,200	2 crown tools
1,149	2,100	3 crown tools 1 crown tool holder 2 parting tools and holders
1,093	2,000	2 crown tools
1,038	1,900	2 crown tools 2 crown tool holders 2 parting tools and holders
982	1,800	2 body tools

Table 3. Gas energy usage under various operating conditions (production evaluation)

Operating condition	First-shift production at normal furnace temperature[a]					First- and second-shift production at reduced furnace temperature[b]				
	Total operating hours	Total gas usage		Average gas usage per hour		Total operating hours	Total gas usage		Average gas usage per hour	
		m^3	scf	m^3	scf		m^3	scf	m^3	scf
Production	198.4	121,082	4,277,000	610	21,558	79.3	36,010	1,272,000	454	16,040
Miscellaneous:										
Hold-loaded	206.1	9,373	3,311,000	455	16,065	43.0	13,249	468,000	308	10,883
Unloading	6.1	3,397	120,000	557	19,672	1.6	679	24,000	425	15,000
Loading	6.5	3,907	138,000	601	21,231	1.3	425	15,000	327	11,538
Startup[c]	144.5	25,026	884,000	173	6,118	29.0	5,181	183,000	179	6,310
Continuous	704.5	325,735	11,506,000	462	16,332	143.5	52,022	1,835,000	363	12,787

[a] 1,204°C (2,200°F)

[b] 1,092°C (2,000°F)

[c] 28.9 hours average startup time

Table 4. Electricity usage under various operating conditions

		First-shift production at normal furnace temperature[a]					First- and second-shift production at reduced furnace temperature[b]				
			Total electricity usage		Average electricity usage per hour			Total electricity usage		Average electricity usage per hour	
Equipment	Operating condition	Total operating hours	MJ	kWh	MJ	kWh	Total operating hours	MJ	kWh	MJ	kWh
Press:	—	198.4	378,004	105,001	1,904	529	79.3	151,546	42,096	1,912	531
Furnace:	Production	198.4	63,691	17,692	320	89	79.3	24,113	6,698	306	85
	Miscellaneous:										
	Hold-loaded	198.5	59,645	16,568	299	83	43.0	11,513	3,198	266	74
	Unloading	6.1	2,030	564	331	92	1.6	479	133	299	83
	Loading	6.5	1,922	534	295	82	1.3	270	75	209	58
	Startup[c]	144.5	41,796	11,610	292	81	29.0	8,132	2,259	281	78
	Continuous	704.5	203,922	56,645	289	80	143.5	42,142	11,706	293	82

[a] 1,204°C (2,200°F)

[b] 1,092°C (2,000°F)

[c] 28.9 hours average startup time

Table 5. Power demand at normal and reduced furnace temperatures for various operating conditions

Equipment	Operating condition	Power demand (kW) Normal furnace temperature[a]	Reduced furnace temperature[b]
Furnace:	Production	89	84
	Hold-loaded	82	77
	Startup	77	77
Press:	Idling	420	420
	Preform	624	552
	Pierce	624	648
	Draw	936	984
	Combined pierce-and-draw	1056	1104

[a] 1,204°C (2,200°F)

[b] 1,092°C (2,000°F)

Table 6. Press loads and mult temperatures at normal and reduced furnace temperatures

	Normal furnace temperature				Reduced furnace temperature			
	Press load		Mult temperature		Press load		Mult temperature	
Operation	MN	tons	°C	°F	MN	tons	°C	°F
Preform								
Min	3.016	339	1,098.8	2,010	4.021	452	1,037.7	1,900
Max*	8.638	971	1,015.5	1,860	8.638	971	987.7	1,810
Avg	5.062	569	1,093.3	2,000	5.925	666	998.8	1,830
Pierce								
Min	4.021	452	1,115.5	2,040	5.631	633	1,054.4	1,930
Max*	8.843	994	1,037.7	1,900	8.443	949	987.7	1,810
Avg	5.231	588	1,093.3	2,000	6.859	771	998.8	1,830
Draw								
Min	0.988	111	1,093.3	2,000	1.130	127	1,026.6	1,880
Max	1.521	171	1,015.5	1,860	1.699	191	960.0	1,760
Avg	1.228	138	1,093.3	2,000	1.272	143	998.8	1,830

* Maximum loads listed are overload forces; therefore, true maximum forces could not be established.

Table 7. Tool usage in forge and rough-turn operations

	Normal furnace temperature Avg pieces-per-tool	Reduced furnace temperature Avg pieces-per-tool	% change
Forge tooling			
Preform punch	6,764	6,869	+ 1.5
Die insert	13,973	13,739	- 1.7
Pierce tip	1,367	1,162	-15.0
Ejector tip	1,394	1,379	- 1.1
Draw mandrel	1,697	1,629	- 4.0
Draw rings	54,227	15,143	-72.1
Rough-turn tools			
Parting			
V-blade	1,182	732	-38.0
Insert	125	109	-12.8
Body insert	109	85	-22.0
Crown insert	175	161	- 8.0
Matching insert	1,264	865	-31.6
Base tool	145	118	-18.6
Center drill	3,793	1,213	-68.0

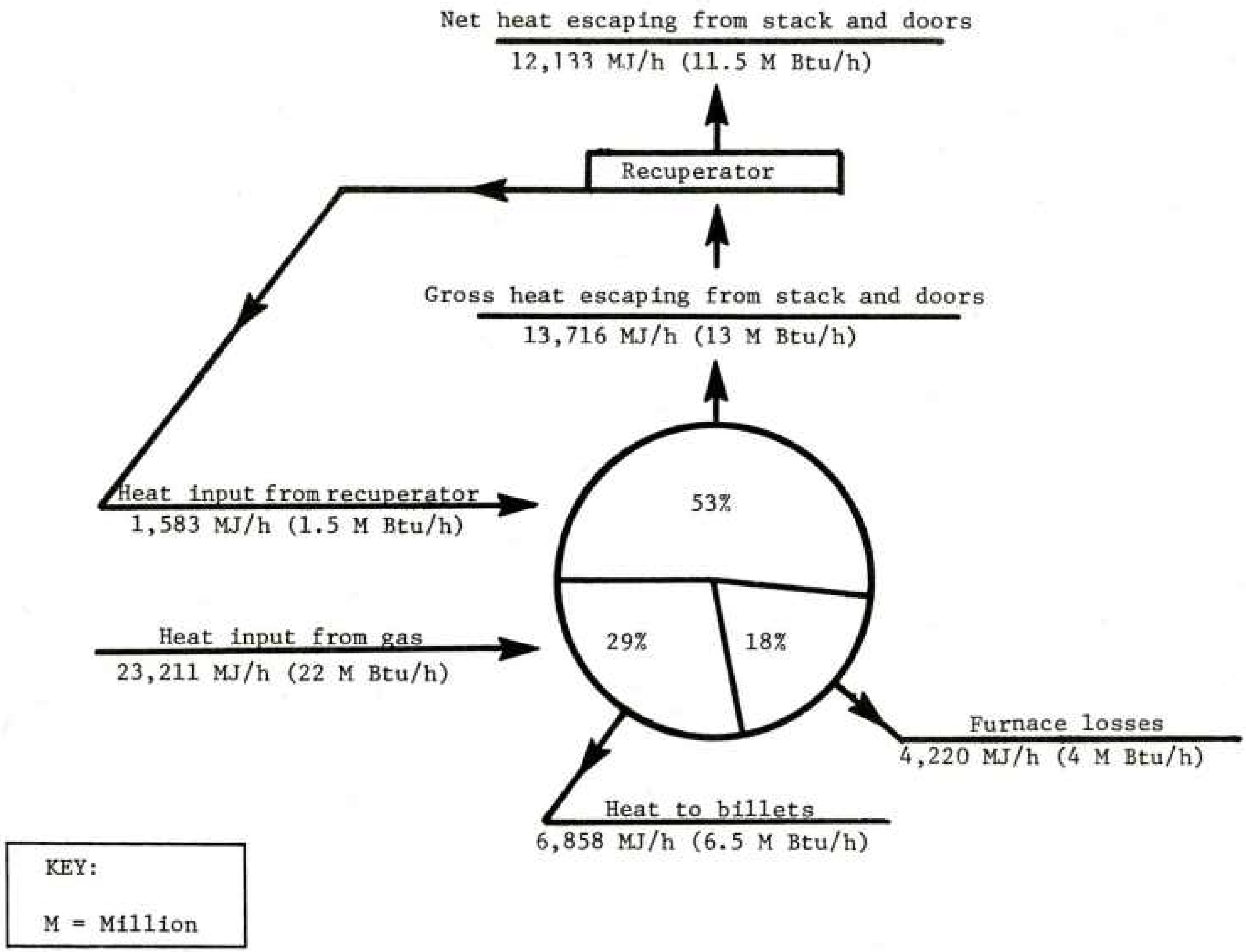

Figure 1. Heat balance for rotary-hearth furnace

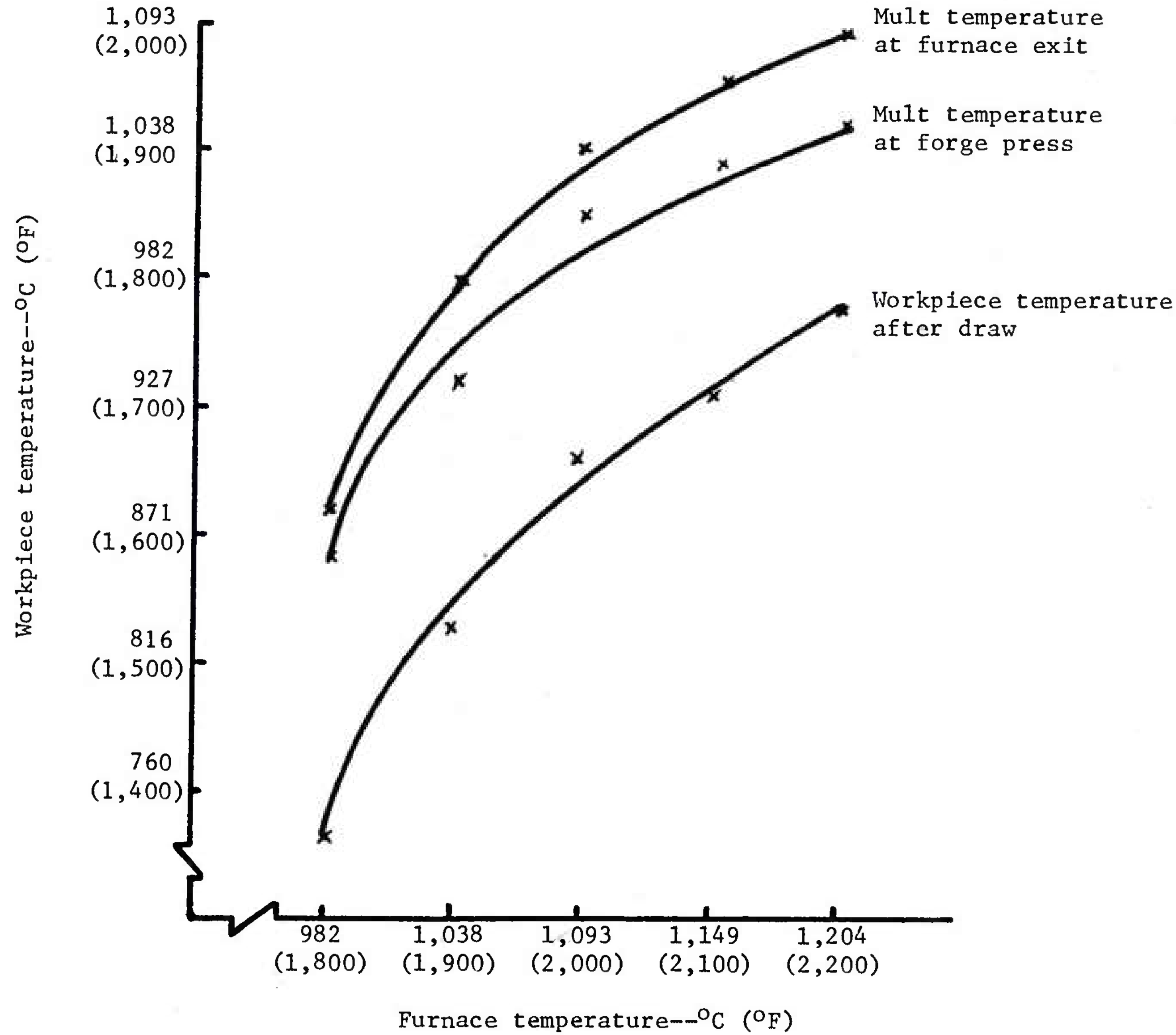

Figure 2. Furnace temperature vs workpiece temperature

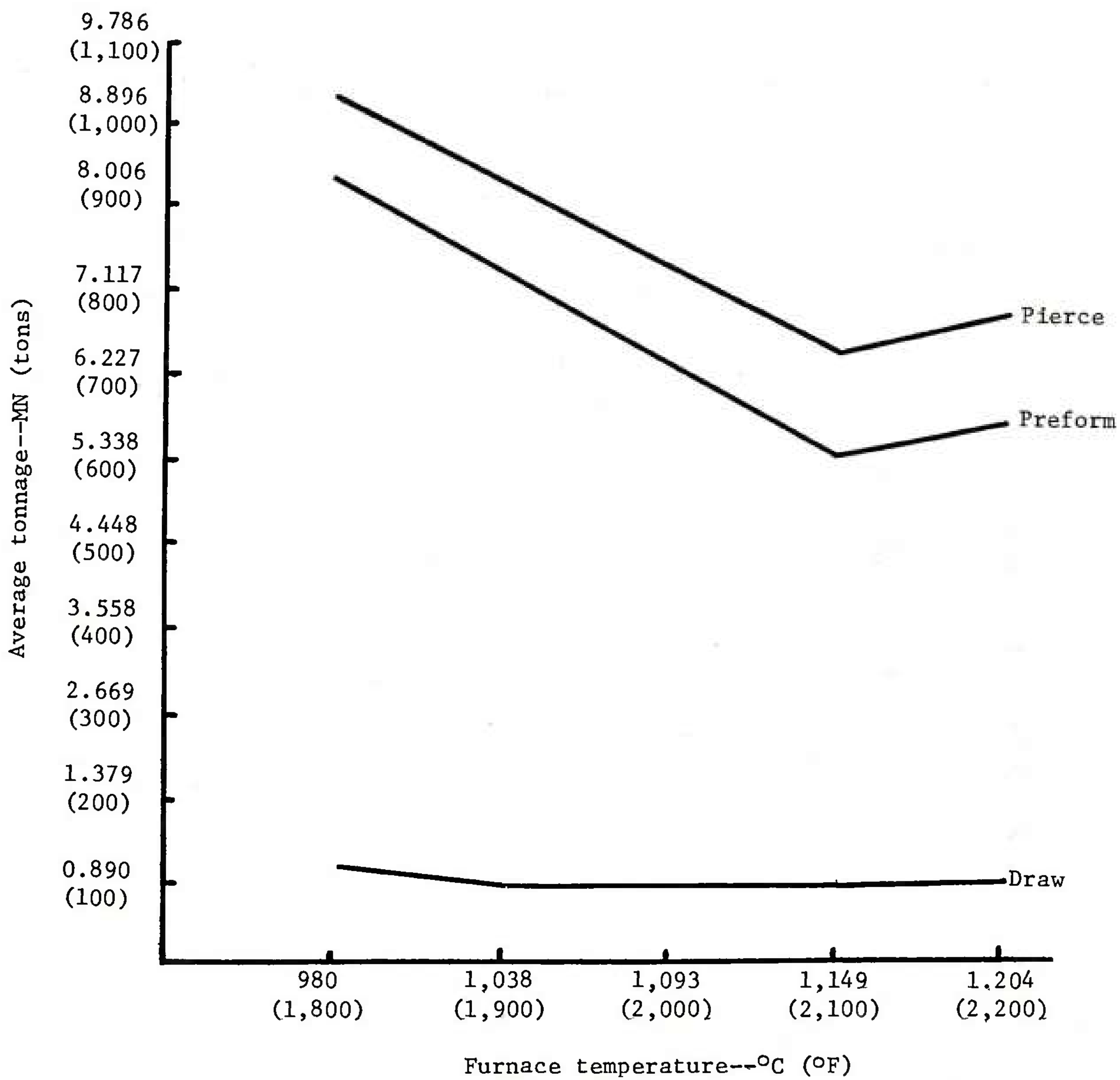

Figure 3. Press tonnage vs furnace temperature

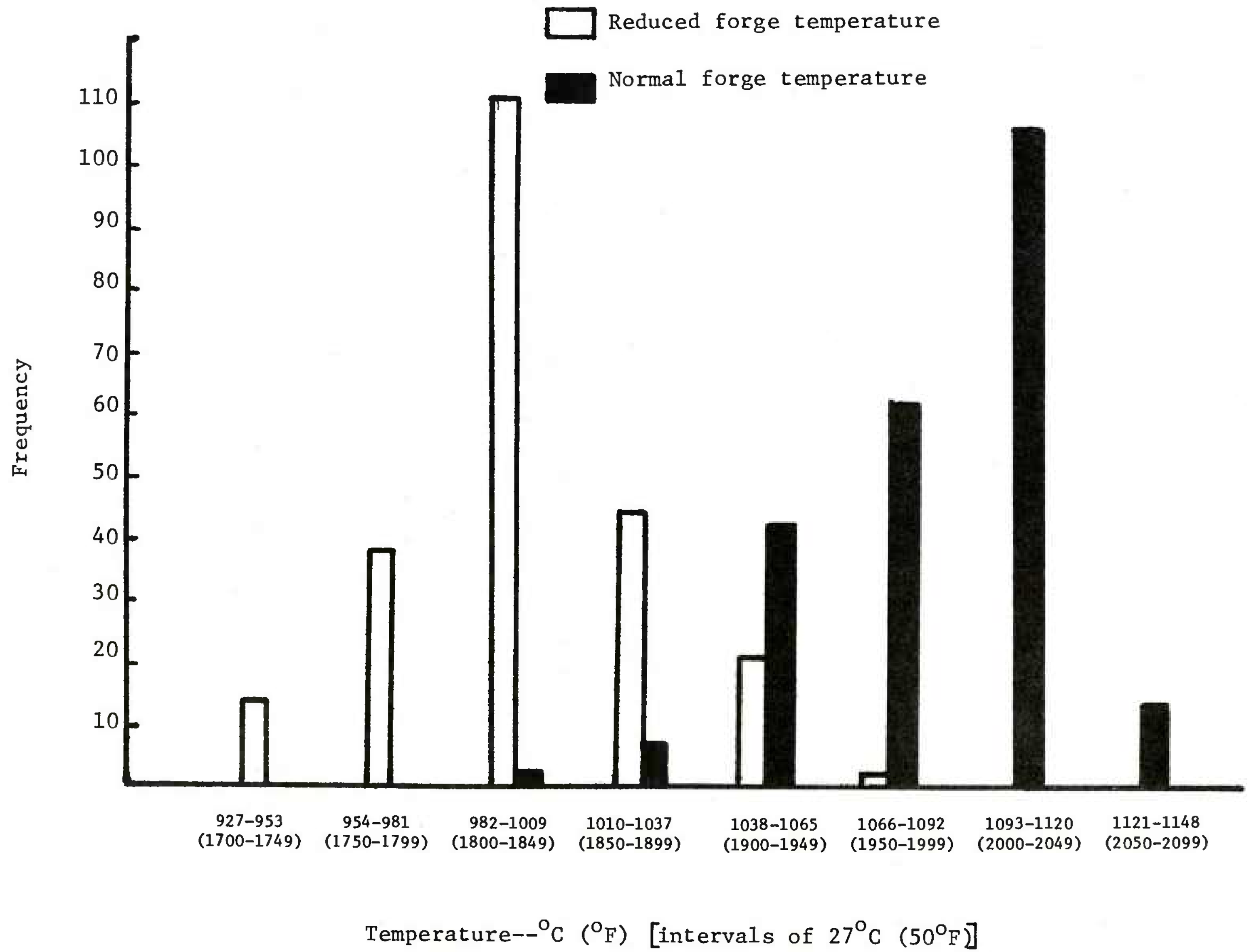

Figure 4. Frequency of mult temperature measurements within specific mult temperature intervals

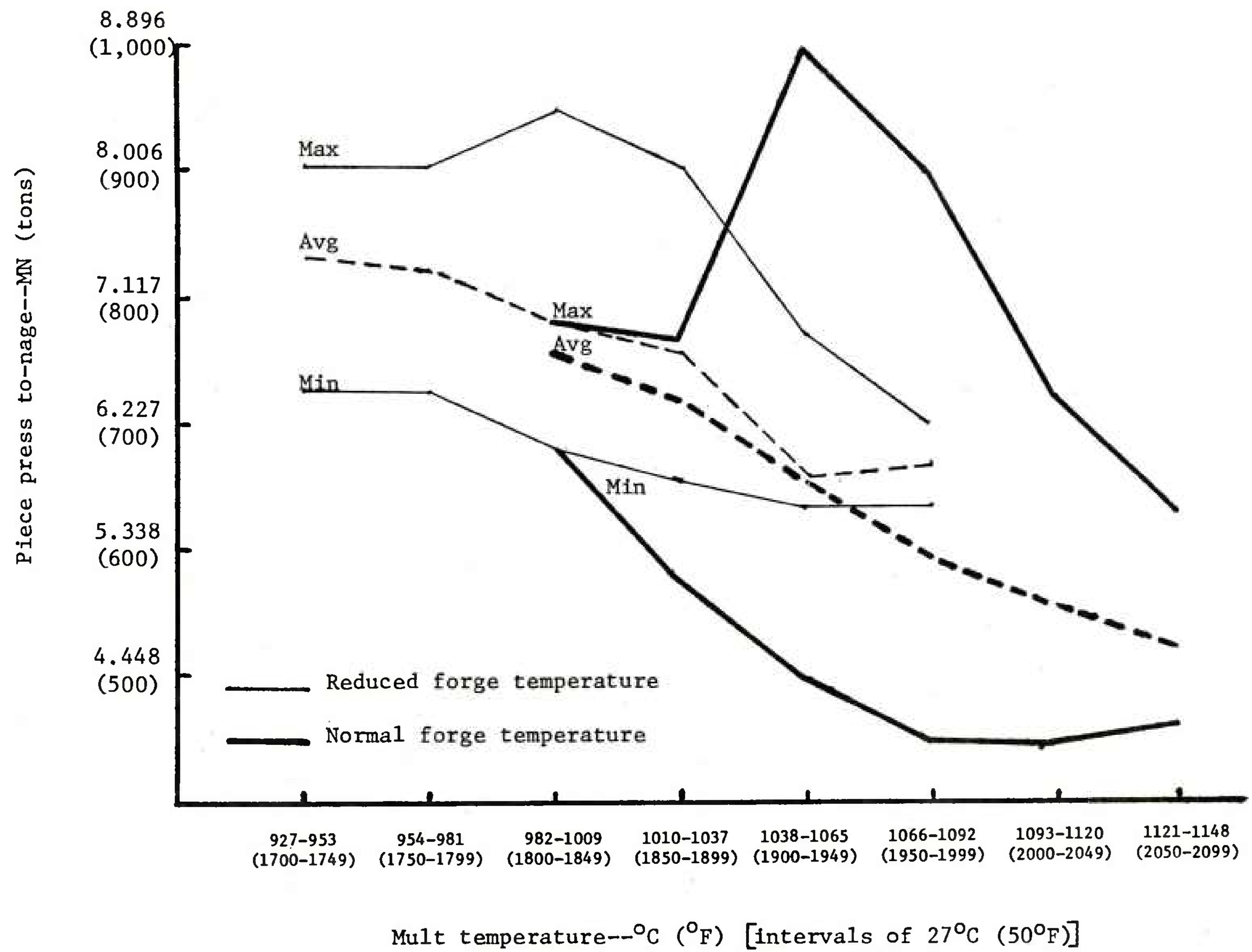

Figure 5. Pierce press tonnage within specific mult temperature intervals

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